INJURIES TO CHILDREN RESTRAINED IN 2- AND 3- POINT BELTS

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ABSTRACT

Injury risks to children restrained in 2-point belts have been well described. "Seat belt syndrome," associated with the use of 2-point belts, includes contusion of the abdominal wall, fracture of the lumbar spine, and intra-abdominal injury. Using crash reconstruction methodologies and prospectively collected clinical data, we compared injury patterns by restraint type among a sample of 98 belted children. There were no significant differences in injury severity or hospital charges by belt type. There was no difference in the risk of AIS ≥ 2 injury to the head, neck, chest, abdominal contents or extremities by belt type. Children restrained in 3-point belts exhibit a similar pattern of injury to those in 2-point belts, however 3-point belts appear to be protective for lumbar fracture.

THE EFFICACY OF SAFETY BELTS in lowering fatality rates and reducing the risk of serious injury to children in motor vehicle crashes is well documented [Niemcryk 1997, Chipman 1996, Johnson 1994, Centers for Disease Control 1991, Kraft 1990, Partyka 1988, Decker 1984, Morris 1983]. Correct use of safety belts can prevent ejection and minimize occupant contact with the vehicle interior during a collision [King 1995, Martinez 1994]. In addition, safety belts are designed to disperse the crash forces over a longer period of time both through the stretching of the belt webbing and, by anchoring the occupant to the vehicle, maximizing the total ride-down distance as the vehicle deforms during a crash [Hill 1993].

The use of safety belts by US children has increased markedly over the last 20 years. While notable reductions in mortality associated with increased restraint usage have occurred in the general population, mortality rates for children between the ages of 5 and 15 have not fallen as quickly as they have for other segments of the population [Graham 1998]. According to the National Highway Traffic Safety Administration (1996), the fatality rate for adolescents 16-20 years has declined approximately 25% between 1975 and 1996, while mortality for children aged 5-9 and 10-15 years has declined only 14% and 11% respectively. Even more striking are changes in injury rates. From 1988-1996, the injury rate per 100,000 children aged 10-15 remained essentially unchanged; for children aged 5-9 years, there was a 20% increase in the injury rate.

Safety belts are designed primarily for adult occupants, however most US state laws allow children to be legally restrained in safety belts once they weigh at least 40 pounds, far less than the 103-pound, 5% female specified in performance criteria. There are several reasons to believe that safety belts may be less effective protecting children than adults. Children, with their smaller body mass, may not load the belts sufficiently to induce stretching of the belt webbing and thus may decelerate more abruptly. Additionally, anatomic differences make it much more difficult to ensure proper belt fit in children. The anterior superior iliac crest, which anchors the lab belt in an adult, does not fully develop until adolescence, this results in the belt's riding cephalad over the abdominal viscera. This, coupled with children's more kyphotic spine, may increase the likelihood of "submarining" under the lap belt in the event of a crash. Finally, the child's more compliant rib cage may permit greater transfer of crash forces to the underlying thoracic organs. Evidence of the reduced efficacy of three-point belts in restraining young children is suggested by Agran, et al., (1992) who compared mean Injury Severity Scores for restrained and unrestrained children. For children aged 4 to 9 years, they found no difference in mean Injury Severity Score between unrestrained children in the right front seat and those restrained in 3-point belts, however a significant difference was seen for older children aged 10 to 14 years.

SEAT BELT SYNDROME -- Injuries associated with loading by the lap belt were first described in 1956 by Kulowski and Rost. The term "seat belt syndrome" was coined in 1963 by Garrett and Braunstein to describe the distinctive pattern of injury including contusion or abrasion of the abdominal wall, fracture of the lumbar spine, and injury to the abdominal viscera occurring to occupants restrained by 2-point belts. Many authors have noted the frequency with which these injuries occur in children [Shoemaker 1997, Lane 1994, Stylianos 1990, Newman 1990], several have detailed problems with diagnosis and treatment of injury to the abdominal organs

[Lynch 1996, Tso 1993, Sivit 1990, Stylianos 1990] and fracture of the lumbar spine [Voss 1996, Greenwald 1994, Glassman 1992, Johnson 1990] specific to pediatric populations. Greater use of 3-point restraints is often cited as a preventive measure for seat belt syndrome in children [Shoemaker 1997, Lane 1994, Stylianos 1990, Johnson 1990].

While there has been no comprehensive review of restraint-related injuries to children from 3-point belts, several authors have published reports of cervical injury to children associated with 3-point belt use [Lynch 1996, Givens 1996, Huelke 1993, Agran 1990]. Tso (1993) described 4 cases of abdominal injury, although no cervical injuries, among 9 children restrained in 3-point belts who were admitted to a pediatric trauma center with crash-related injuries. This study compares the risk of belt-related injury among 98 children restrained in 2- or 3-point belts who were injured in motor vehicle crashes.

METHODS

All belted children aged 0 to 15 years who were consecutively admitted to Children's National Medical Center, a regional pediatric trauma center in Washington, DC, between December 1991 and December 1997 were eligible for inclusion. Excluded from the sample were children who were restrained only by shoulder belts, right front seat passengers who experienced air bag deployments, children in vehicles more than six years old at the time of admission, and cases in which the vehicle could not be located; no exclusions were made by principle direction of force.

After parental consent was obtained, all injuries were documented and photographed, and the heights and weights of the children were recorded. Data concerning injury diagnosis, injury severity, medical treatment and outcome were collected prospectively during the child's acute treatment and follow-up. Injury severity was measured using the Abbreviated Injury Scale, the Injury Severity Score, the Revised Trauma Score and the TRISS probability of survival.

Crash reconstructionists were notified of the time and location of the crash immediately after informed consent was secured; notification typically occurred within 36 hours of the crash. The reconstructionists visited the scene of the crash, examined the damaged vehicles, reviewed police accident reports, and interviewed family members and pre-hospital providers in order to reconstruct the factors leading to the crash and the movements of the vehicles and their occupants immediately following impact. Measurements of post-crash vehicle dimensions for overall length, width, wheelbase, maximum crush, and front and rear overhang were compared to manufacturers' specifications. Vehicle deformity measurements were used to estimate the total, longitudinal, and lateral velocity changes

(Delta V) experienced by the vehicle. Restraint use was determined by the presence of belt marks on the child's torso, physical signs of belt wear such as evidence of stretched webbing or deformed anchor ridges, and interviews with providers of pre-hospital medical services, vehicle occupants, and the children themselves. Monthly case review meetings were held among pediatric surgeons, orthopedists, radiologists, nurses, crash reconstructionists, engineers, and traffic safety advocates to determine the most likely mechanisms responsible for each injury the child sustained and to establish the correctness of restraint use.

Patterns of belt-related injury for children in 2- and 3-point belt systems were compared. Children who had placed the shoulder belt behind their backs were grouped with those in 2-point belts; children who placed the shoulder belt under their arms were classified with those wearing 3-point restraints. Mean values of injury severity measures by restraint type were compared using Student's t test. Odds ratios and 95% confidence intervals were computed by restraint use for belt-related injuries to the chest and abdomen and for any injury to the head, neck, or extremities. The cumulative probabilities of intra-abdominal injury by height, weight, and Delta V were platted by restraint type.

RESULTS

A total of 98 belted children were included in the study. The mean age of the children in the sample was 7.3 years (± 2.5). Half of the children were aged 6 years or younger; 72% were between the ages of 5 and 9 years. The mean height was 121.7 cm (± 17.8), the mean weight was 27.9 kg (± 11.5). Nearly 60% of the children were girls (n = 57).

The children were equally distributed by restraint type, with 49 children in 2-point belts and 49 in 3-point belts. Restraint type was evenly distributed by age, as shown in Figure 1. The children were evenly divided by seating position, with half (n = 49) in the right front seat, and half in rear seating positions. Two-thirds (n = 66) of the children were injured in frontal crashes, 21% (n = 21) in lateral crashes, 7% in rollover (n = 7) and 4% (n = 4) in rear collisions.

TYPES OF INJURY -- The types of belt-related injuries by restraint type are listed in Table 1. External abrasions and contusions to the chest and abdomen (AIS = 1) were the most common. The likelihood of external abrasion increased directly both with the weight of the child and the computed Delta V.

Table 1. Frequencies and types of belt-related injury by restraint type.

Injury	2-point belt	3-point belt
Thoracic Injuries		
External abrasions/contusions	0	7
Rib/Sternal fractures	0	0
Clavicle fracture	0	1
T-spine fracture	0	1
Pneumothorax	1	1
Lung contusion	0	1
Abdominal Injuries		
Abrasions/Contusions	9	7
L-spine fracture	9	0
Stomach, perforation/tear	2	0
Small intestine, hematoma	2	2
Small intestine, perforation/tear	3	3
Small intestine, rupture/transection	0	2
Colon, hematoma	2	0
Colon, laceration	3	3
Mesentery, hematoma	0	3
Mesentery, laceration	0	1
Bladder, rupture	1	0
Liver, laceration	0	2
Spleen, hematoma	1	2
Spleen, laceration	1	2
Pancreas, hematoma	2	0
Peritoneal hematoma	1	1
Kidney, hematoma	0	1
Kidney, laceration	0	1
Adrenal hematoma	0	1
Retroperitoneal hematoma	1	2

There were no fractures of the sternum or ribs attributed to belt loading experienced by the children in this sample, however there was one clavicular fracture. There were no belt-related injuries to the heart or great vessels. Three of the 4 belt-related injuries involving the thoracic cavity were to children in 3-point belts.

Lumbar fractures were the most common belt-related abdominal injury, all 9 of which were sustained by children in 2-point belts. One child, who was restrained in a 3-point belt in the left rear seat in a right offset frontal crash, sustained a compression fracture at T-12/L-1. There were a total of 45 belt-related intra-abdominal injuries, over half of which (n = 23) were to the hollow viscera. The 10 children with solid

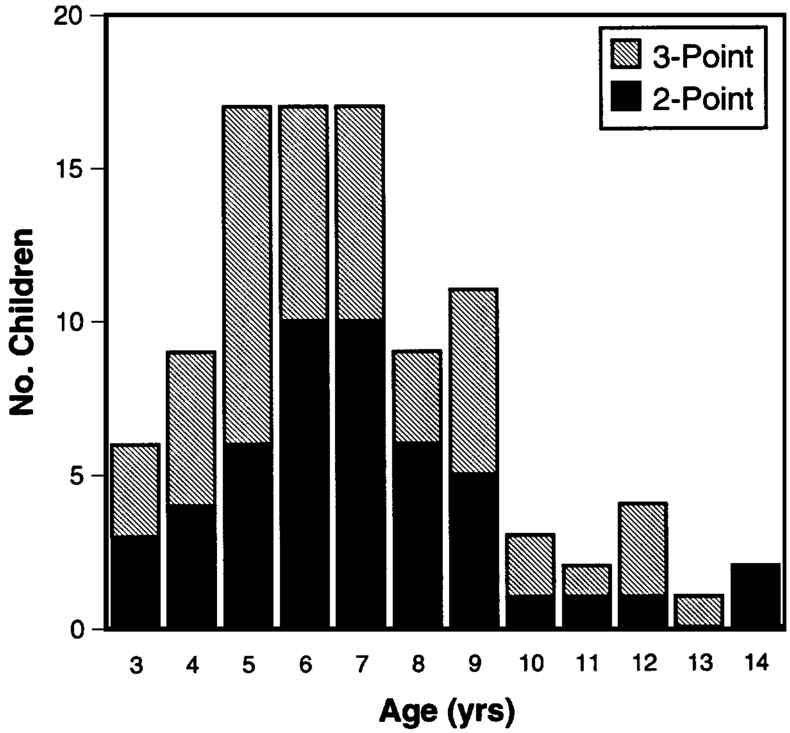

Figure 1. Distribution of belt type by age of child.

organ injuries were nearly evenly distributed between children in 2- and 3-point restraints (4 versus 6, respectively). Five of the 6 retroperitoneal injuries were sustained by children in 3-point restraints.

There was one cervical injury > AIS 1. A child restrained in a 3-point belt sustained a subarachnoid hematoma at the C-1 level as the result of a rollover; the injury resulted in hemiparalysis that resolved over 9 months.

INJURY SEVERITY -- The mean Injury Severity Score was 9.6 (±12.0). The children arrived at the trauma center in relatively stable physiologic condition as indicated by a mean Revised Trauma Score of 7.17 (±1.37); the mean TRISS probability of survival was 0.921 (± 0.219). One child, who was seated on the struck side of a lateral crash died of injuries unrelated to belt use; there were no fatalities from belt-related injuries.

There were no differences among any of the injury severity measured studied by belt type (See Table 2.). The somewhat higher, but not statistically significant, hospital charges for children in 2-point belts are due largely to the statistical leverage exerted by a single charge of more than $270,000.

Table 2. Mean values for indicators of injury severity by restraint use.

Injury Descriptors	2-point Belts mean (S.D.)	3-point Belts mean (S.D.)	p value
Injury Severity Score	9.3	10.0	0.76
Revised Trauma Score	7.23 (1.20	7.12 (1.54)	0.72
TRISS P(s)	0.919 (0.22)	0.922 (0.23)	0.95
Glasgow Coma Scale	14.1 (3.1)	13.8 (3.2)	0.63
Maximum AIS	2.1 (1.6)	2.3 (1.9)	0.49
Length of Stay (d)	5.9 (8.8)	4.1 (5.4)	0.23
Hospital Charges ($US)	25,611 (47,118)	14,682 (19,648)	0.15

BODY REGION INJURED -- Children restrained in 3-point belts experienced no difference in risk of injury (AIS ≥ 2) to the head, face, chest, abdomen, or extremities, as shown in Table 3. The odds of lumbar spine fracture were 9 times higher for children restrained by the lap belt only compared with those in 3-point belts (95% C.I. 1.2, 68.4).

Table 3. Relative odds of injury by body region for children in 3-point versus 2-point belt systems.

Body Region Injured (AIS ≥ 2)	Relative Odds	95% Confidence Interval	
Head	1.50	0.81	2.77
Face	0.25	0.03	2.16
Chest†	1.00	0.31	3.24
Abdomen†	0.92	0.47	1.82
Lumbar Spine†*	0.11	0.01	0.84
Extremities	1.57	0.66	3.72

† Belt-related injuries only

* Includes child with T-12/L-1 compression fracture

OCCUPANT CHARACTERISTICS -- There were no gender-related differences in restraint system usage or injury rate; 35% of the girls (n = 20) and 24% of the boys (n = 10) sustained belt related injuries (p = 0.26).

The child's height was not associated with risk of belt-related intra-abdominal injury (AIS ≥ 2). An association between the risk of injury to abdominal organs and weight is suggested by a nearly linear inverse relationship, although this was not statistically significant (See Table 4.). The empirical cumulative probability plots of belt-related AIS ≥ 2 abdominal injury (including lumbar fracture) by belt type are nearly identical for body height and weight (See Figures 2 and 3.).

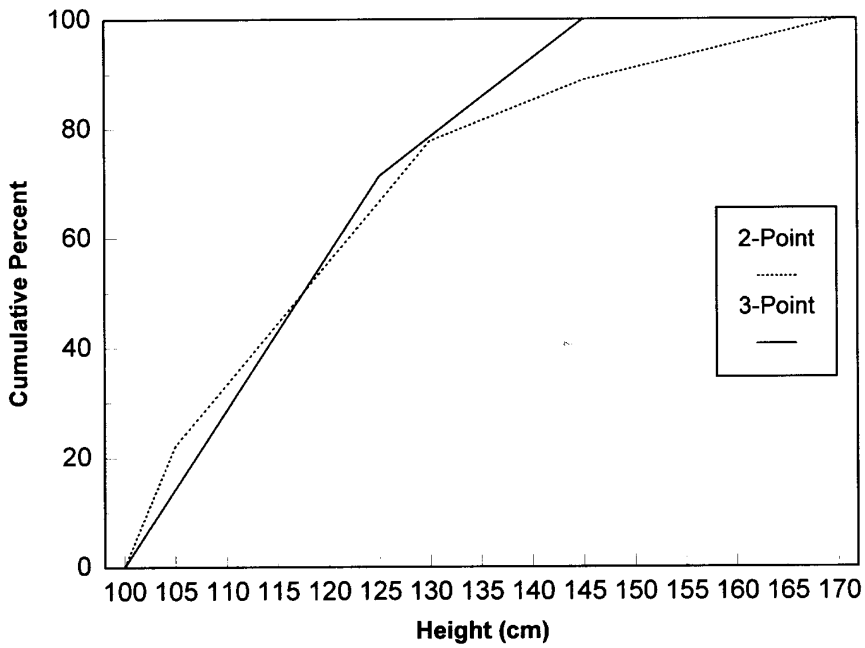

Figure 2. Cumulative probability of belt-related abdominal injury by height of child and restraint use.

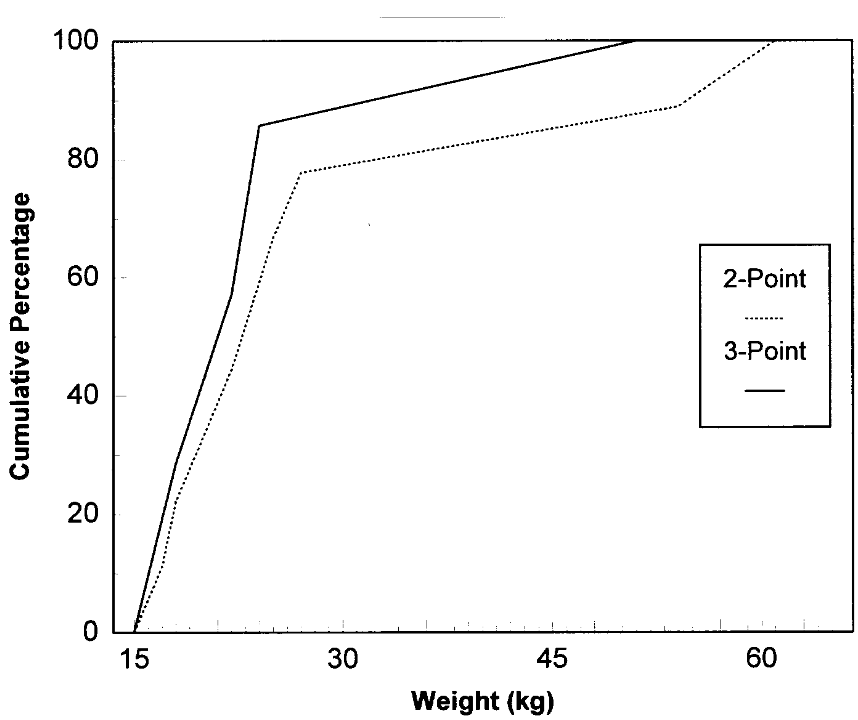

Figure 3. Cumulative probability of belt-related abdominal injury by weight of child and restraint use.

Table 4. Rate of belt-related abdominal injury (AIS ≥ 2) by weight.

Weight (kg)	n	AIS ≥ 2 (n)	%
< 20	22	8	36.4
20-24	25	7	28.0
25-29	19	5	26.3
30-34	13	2	15.4
35-44	9	2	22.2
≥ 45	10	1	10.0

(Mantel-Haenzel chi-square 2.96; $p = 0.08$)

RESTRAINT MISUSE – Incorrect use of the belt systems was common. Of the children classified as having 2-point restraints, 47% (n = 23) were restrained in 3-point belts with the shoulder belt routed behind their backs. Seven (14%) of the children in 3-point belts had the shoulder belt routed under their arm to keep the belt away from the child's face. Two pairs of children were "doubled up," restrained in a single lap belt. Because of the limitations of retrospective restraint use reconstruction, it was not possible to uniformly determine whether safety belts were worn too loosely.

Among belted children, incorrect restraint use was not associated with increased risk of belt-related injury. For children restrained by the lap belt only, there was no significant difference in injury risk between those in 2-point belts (27% of whom sustained belt-related injury) and those who wore the shoulder portion of their 3-point restraint behind their backs (35% of whom sustained belt-related injury).

One of the 7 children who had the shoulder belt routed under the arm sustained belt-related injuries (liver contusion and intestinal rent). There was no difference in the risk of belt-related injury for children wearing their shoulder belts in the "under-the-arm" configuration versus those wearing the belts across the upper torso. The small number of children exhibiting this belt misuse pattern does not support a more detailed analysis.

SEATING POSITION -- There was no difference in risk of injury to the chest or abdomen by front versus rear seating position. While children in the rear seating positions appeared to be at greater risk of injury to the lumbar spine (16.3% vs. 4.1%; $p < 0.05$), this difference disappeared after adjusting for the increased use of 2-point restraints by rear seat occupants.

CRASH SEVERITY AND TYPE – Children in 2- and 3-point belts experienced crashes of similar type and severity, as indicated by the lack of significant difference either in mean Delta V (32.6 km/h vs. 33.9 km/h; $p = 0.67$) or in the distribution of front, lateral, rear, and roll-over crashes between the two groups. There was no difference in risk of belt-related injury by crash type.

The risk of belt-related injury increased with increasing Delta V, for children in both belt systems, as shown in Table 5. Likewise, the cumulative probability plots for belt-related abdominal injury by Delta V indicates no clear difference in risk of belt-related injury by restraint type. However, the data suggest that for crashes with a Delta V greater than 35 km/h the risk of abdominal injury may be greater for children in 2-point belts (See Figure 4.).

Table 5. Belt-related injury by crash severity and belt type.

	2-point Belts		3-point Belts		
Delta V (km/h)	n	% injured	n	% injured	p value
< 20	21	19.0	23	13.0	0.59
20-24.9	14	35.7	13	38.5	0.88
≥ 25	12	50	10	50	1.00

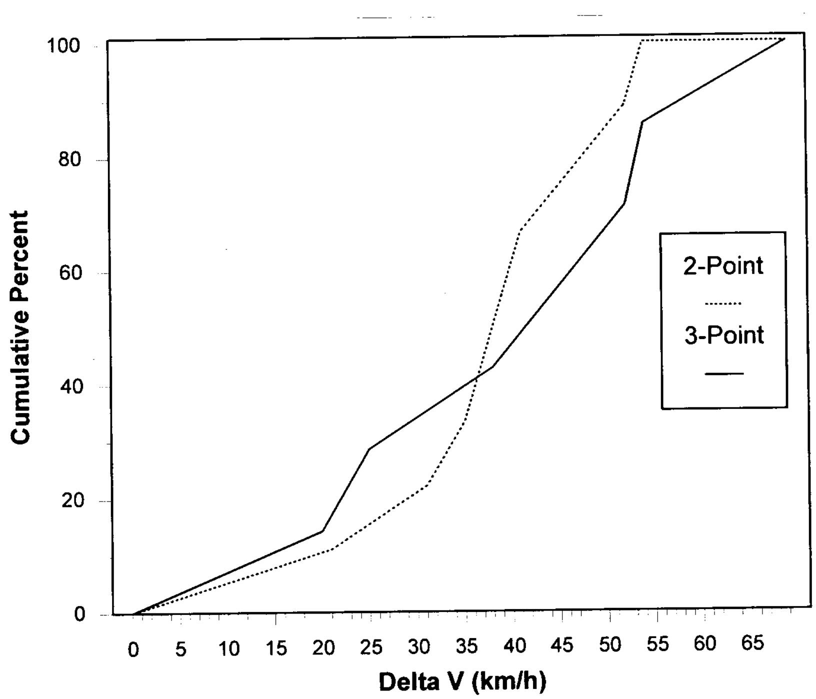

Figure 4. Cumulative probability of belt-related abdominal injury by crash severity and restraint use.

DISCUSSION

A distinctive pattern of injury to children restrained in 3-point belts is emerging. Contusions to the abdominal wall and intra-abdominal injuries are common and seem to occur with the same frequency as are found in children restrained by lap belts only. While the use of 3-point belts greatly reduces the risk of fracture to the lumbar spine, use of the restraints may increase the risk of injury to the kidney, liver, and spleen, as 8 of 10 children sustaining these solid organ injuries were so restrained. Tso (1993) also reported a higher percentage of solid organ injuries for children in 3-point versus 2-point belts. There may also be increased risk of injury to the thoracic viscera, however larger databases will be required to fully assess the risk of these less common injuries. In contrast with studies of belt related injuries in adults [Hill 1994, Martinez 1992], there were no cases of rib or sternal fractures resulting from belt loading in this series, although there was one clavicular fracture. Differences in thoracic injury patterns between children and adults may be attributed to the child's more compliant rib cage.

Givens (1996) has suggested that children in 3-point belts are at increased risk of injury to the cervical spine, however Huelke (1993) states that these injuries are extremely rare. Agran, et al., (1987) reported that 21% of all children restrained by 3-point belts during motor vehicle crashes suffer cervical strains. Cervical injuries have also been reported for children in 2-point restraints [Lynch 1996, Tso 1993, Williams 1993]. At this time there is insufficient data to comment on the risk of cervical injury relative to belt type.

Comparisons of risks of intra-abdominal injury for adults wearing 2- and 3-point belts indicate a marked decrease in injury risks for those restrained in 3-point belts [Huelke 1993, Anderson 1991], in contrast to our findings in children. The reasons for children's higher risk may stem from a combination of poor fit of the shoulder belt and anatomic differences. The three principle injury mechanisms postulated for belt-related hollow viscus injury are compression of the viscera between the belt and the spine, shearing due to deceleration of organs with fixed points of attachment, and transient changes in interlumenary pressure [Hill 1993, Asburn 1990, Williams 1963]. The small antero-posterior diameter of children and their relatively thinner abdominal wall [Newman 1990] put them at greater risk of abdominal injury which may not be mediated by restraint of the upper torso provided by shoulder belts. In addition, it is difficult to obtain proper fit of the shoulder belt on a small child, often resulting in the shoulder belt's fitting loosely, especially in vehicles with door-mounted upper anchorages. When the shoulder belt is loose or does not fit properly, the child may load predominately on the lap belt, resulting in an injury pattern similar to that when no shoulder belt is present.

This sample includes children who have misused their safety belts either by placing the shoulder belt behind their backs or by placing the shoulder belt under their arm. Although such belt misuse may degrade belt performance, we have chosen to include these children in our sample in order to provide a broader picture of belt-related injuries as they occur in “real world” crashes. Similarly, we have chosen to include children injured in all crash configurations, not only those in frontal crashes, as we found the risk of belt-related injury to be independent of crash type, given that an injury was sustained. In trying to develop a clearer understanding of how children are injured in crashes, we believe it is important to investigate all belt-related injuries regardless of restraint misuse or crash type. We believe that the drawbacks of this focus are minimized in this sample by the lack of significant difference in the risk of belt-related injury found either by belt misuse or by crash type.

While the data presented here indicate that 3-point belts may pose a greater injury risk to children than previously believed, caution must be exercised in interpreting the results. The sample, while considerably larger than previously published reports on injuries to children related to the use of 3-point belts, nonetheless is relatively small, and does not support detailed analysis for most specific types of injury. Additionally, by excluding from the sample belted children who were uninjured in motor vehicle crashes, it is impossible to meaningfully compare the relative efficacy of the two restraint systems. Further research using larger databases is needed to better understand the contribution of 3-point restraints to belt related injuries in children.

Although infants, toddlers, and adults typically use restraint systems specifically designed to meet their anatomical needs, children who have outgrown safety seats do not. Belt systems designed for adults do not afford effective for the school aged child as much protection as safety seats do for the preschool child. While use of safety seats has been found to reduce injuries by 60% for children aged 0 to 4 years, 3-point belts have been shown to reduce injuries by only 38% or children aged 5 to 14 years [Johnson 1994].

The American Academy of Pediatrics and the National SAFE KIDS Campaign recommend that a booster seat be used when a child has outgrown a convertible safety seat, but is too small to fit in a vehicle safety belt. Booster seats are available, but they are not yet widely used in the US, and no state or territory mandates their use. Furthermore, because of limited market demand and a lack of appropriate safety standards and testing dummies, very few booster seats are approved for use by children weighing more than 60 pounds, despite the recent recommendation of the NHTSA that children remain in booster seats until they are at least 80 pounds. This study supports the need for continued educational efforts promoting the use of booster seats for children who have outgrown traditional safety seats and further supports the need for development of booster seats and safety standards to provide better protection for children weighing more than 60 lbs.

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